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AN EIGHT-WEEK GOLF-SPECIFIC EXERCISE PROGRAM IMPROVES PHYSICAL CHARACTERISTICS, SWING MECHANICS, AND GOLF PERFORMANCE IN RECREATIONAL GOLFERS

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ABSTRACT. Lephart, S.M., J.M. Smoliga, J.B. Myers, T.C. Sell, and Y.-S. Tsai. An eight-week golf-specific exercise program improves physical characteristics, swing mechanics, and golf performance in recreational golfers. *J. Strength Cond. Res. 21(3): 860—869. 2007.*—The purpose of this study was to determine the effects of an 8-week golf-specific exercise program on physical characteristics, swing mechanics, and golf performance. Fifteen trained male golfers (47.2 ± 11.4 years, 178.8 ± 5.8 cm, 86.7 ± 9.0 kg, and 12.1 ± 6.4 U.S. Golf Association handicap) were recruited. Trained golfers was defined operationally as golfers who play a round of golf at least 2–3 times per week and practice at the driving range at least 2–3 times per week during the regular golf season. Subjects performed a golf-specific conditioning program 3–4 times per week for 8 weeks during the off-season in order to enhance physical characteristics. Pre- and posttraining testing of participants included assessments of strength (torso, shoulder, and hip), flexibility, balance, swing mechanics, and golf performance. Following training, torso rotational strength and hip abduction strength were improved significantly ($p < 0.05$). Torso, shoulder, and hip flexibility improved significantly in all flexibility measurements taken ($p < 0.05$). Balance was improved significantly in 3 of 12 measurements, with the remainder of the variables demonstrating a nonsignificant trend for improvement. The magnitude of upper-torso axial rotation was decreased at the acceleration ($p = 0.015$) and impact points ($p = 0.043$), and the magnitude of pelvis axial rotation was decreased at the top ($p = 0.031$) and acceleration points ($p = 0.036$). Upper-torso axial rotational velocity was increased significantly at the acceleration point of the golf swing ($p = 0.009$). Subjects increased average club velocity ($p = 0.001$), ball velocity ($p = 0.001$), carry distance ($p = 0.001$), and total distance ($p = 0.001$). These results indicate that a golf-specific exercise program improves strength, flexibility, and balance in golfers. These improvements result in increased upper-torso axial rotational velocity, which results in increased club head velocity, ball velocity, and driving distance.

KEY WORDS. X-factor, conditioning, training, driving

INTRODUCTION

Golf has become increasingly popular for players of all ages and skill levels, with estimates of more than 55 million golfers around the world (5). Golf not only provides a means of sports and recreation, it also can be a method of improving cardiovascular fitness and balance (19, 23, 30). Optimal physical conditioning has been a central tenet of maximal performance in most sports but has been overlooked in golf. Golf instructors have long appreciated the importance of proper swing mechanics and are just beginning to recognize how physical attributes relate to the swing. Those who play and teach golf are beginning to realize the need for adequate strength, flexibility, and balance training to optimize swing mechanics to enhance golf performance and potentially to prevent injuries (5).

Several key factors for improving golf performance have been identified. Watanabe (32) biomechanically analyzed swings of 22 amateur golfers and reported that skilled players with lower golf scores had higher club head velocity, higher ball launch angle, lower standard deviation of ball velocity, and faster body-twist angular velocity. Burden (2) observed that 75% of sub-10 handicap golfers rotate their shoulders greater than 90° during the backswing. Recently, Doan (3) found training-related improvements in trunk flexibility and a variety of strength measurements to improve golf performance. However, no published study has elucidated how improvement in golf-specific physical characteristics influence swing mechanics and consequently change ball launch characteristics following golf-specific training.

Several studies have implemented strength, flexibility, balance, and warm-up programs to enhance golf performance (3, 6, 8, 13, 15, 16, 26). The programs by Hetu (13) and Thompson (26) consisted of general flexibility and strength exercises for 8 weeks and resulted in a 3–6% increase in club head speed. Using more vigorous strength exercises, plyometric training, and medicine ball exercises, Doan (3) and Fletcher (6) reported increases in club head speed of 1.6 and 1.5%, respectively, as well as a 4.3% increase in driving distance (6). Similar club head speed increases also have been observed after a flexibility training program that demonstrated improvements in trunk rotations and hip-extension range of motion (15). Furthermore, golf-specific strength and flexibility programs emphasizing strength, movement, and balance training improved several variables, including driving distance (16). Fradkin (8) determined that 5 weeks of performing a golf-specific warm-up program increased club head speed. With the exception of Fradkin (8), these training programs were based primarily on golf theory and anecdote and used general conditioning exercises, rather than golf-specific exercises. Additionally, previous training programs did not include swing-mechanics analysis as part of their research design (3, 6, 8, 13, 15, 16, 26).

In order to develop an evidence-based training program, we have collected information on the physical characteristics (strength, flexibility, balance) of more than 100

TABLE 1. Kinematics reliability.*

Positions at top	ICC	*SEM* (°)
Upper torso axial rotation	0.893	2.18
Pelvis rotation	0.877	2.79
X-factor	0.905	3.33
Velocities at acceleration	ICC	*SEM* ($^{\circ}\cdot s^{-1}$)
Upper torso axial rotation	0.571	35.9
Pelvis rotation	0.649	37.7
X-factor	0.731	36.0

* ICC = intraclass correlation.

golfers of various skill and handicap levels and have identified the physical characteristics of better golfers compared with golfers with higher handicaps (20, 27). In general, there was a trend for proficient golfers to have better strength, flexibility, and balance. More specifically, noticeable differences between proficient golfers and golfers with higher handicaps were found in hip abduction strength and torso rotation strength, shoulder horizontal abduction/adduction, shoulder extension, hip flexion/extension, knee-extension range of motion (ROM), and single-leg balance. Based on these data, we aimed to create a golf-specific program to enhance those characteristics that have been determined to predict selected performance parameters, including club head velocity, ball velocity, and driving distance.

Therefore, the purpose of this study was to determine the effects of an 8-week golf-specific exercise program on physical characteristics, swing mechanics, and golf performance of recreational golfers. We hypothesized that this program would induce favorable changes in shoulder horizontal abduction/adduction, shoulder extension, hip flexion/extension, knee extension, torso rotation flexibility, hip abduction and torso rotation strength, and single-leg balance. We also hypothesized that favorable changes in parameters of physical characteristics would result in improved swing mechanics, such as maximal upper-torso rotation position during backswing and maximal upper-torso rotational velocity during downswing. Lastly, we hypothesized that these changes in swing mechanics would result in subsequent increases in ball launch characteristics (club head velocity, ball velocity, and total driving distance).

METHODS

Experimental Approach to the Problem

A group of golfers performed a pre- and posttraining intervention design in which physical characteristics, biomechanical data, and launch characteristics were collected.

Subjects

Fifteen healthy male golfers volunteered to participate in this study. Subjects' mean ± *SD* for age, height, weight, and U.S. Golf Assocation handicap were 47.2 ± 11.4 years, 178.8 ± 5.8 cm, 86.7 ± 9.0 kg, and 12.1 ± 6.4, respectively. These golfers varied in experience levels, with some participating in golf for the majority of their lives and others having a minimum of 3 years' experience. All subjects were trained golfers, operationally defined as playing a round of golf 2–3 times per week and practicing at the driving range 2–3 times per week during the regular golf season. All subjects provided written informed consent as approved by the university Institutional Review Board prior to participation. All subjects completed a general medical history and orthopedic history questionnaire prior to participation to verify they were currently healthy. All testing procedures took place in a university medical center–based human movement research laboratory. The study was conducted during the off-season, and subjects were requested not to receive any golf instruction, not to participate in any golf practice or play, and not to participate in a similar golf-specific conditioning program prior to or at the time of this study. Subjects' adherence to these requests was confirmed at the time of the posttest by examining their training logs.

Testing

Subjects were enrolled in an 8-week conditioning program designed to enhance strength, flexibility, and balance. Specifically, the program aimed to promote the stability of the lower body and to increase the mobility of the upper body. All subjects were tested prior to and following the 8-week conditioning program.

Three-dimensional Biomechanical Analysis. Kinematic data of the golf swing was collected using the Peak Motus System v.7.0 (Peak Performance Technologies, Inc., Englewood, CO). Eight optical cameras (120 Hz) (Pulnix Industrial Product Division, Sunnyvale, CA) were placed at a distance of 4 m around 2 force plates; the capture volume was 3.0 × 4.3 × 2.9 m. Calibration was done using the wand calibration method according to the manufacturer's guidelines. A root-mean-square error of 0.002 m and 0.254° was employed within our laboratory for determining the measurement accuracy of position and angular data. The reliability of the golf-specific kinematics of this system was established previously in our laboratory (Table 1).

Subjects were fitted with reflective markers at the following landmarks: anterior-superior iliac spine (ASIS; bilaterally), sacrum, acromion (bilaterally), and seventh cervical vertebrae (C7). The upper-torso segment was defined by the C7 and acromion markers and the pelvis segment was defined by the sacrum and ASIS markers. Two markers were placed on the golf club to identify the phases of the golf swing. Time for a self-directed warm-up, stretching, and practice shots was provided prior to data collection. Subjects hit golf balls with their own drivers to represent the actual swing pattern experienced while playing. Subjects hit 10 shots off an artificial turf mat into a screen approximately 5 m away.

Golf Ball Launch Analysis. The Vector Launch System (Accusport, Inc., Winston-Salem, NC) was used to collect golf ball launch data during the biomechanical analysis. The system was set up and was tested in accordance with the manufacturer's directions prior to each testing session. A template supplied by the manufacturer was used

TABLE 2. Launch characteristics reliability.

Positions	ICC	*SEM*
Carry	0.706	10.21 m
Roll	0.344	2.56 m
Total	0.738	9.59 m
Ball velocity	0.735	1.69 m·s^{-1}
Club velocity	0.704	1.12 m·s^{-1}
Launch	0.609	2.50°
Backspin	0.60	550.6 rev·min^{-1}
Sidespin	0.399	238.0 rev·min^{-1}

* ICC = intraclass correlation.

to draw a vertical line on each golf ball using a black permanent marker in accordance with the manufacturer's directions. The system used a microphone to determine impact and a high-speed camera to record 2 images of the ball after impact. The system identified the vertical line on the ball for each image and used internal algorithms to compare the line positions to measure ball velocity, launch angle, and backspin rate and to calculate club head velocity, carry distance, and total distance. Data were collected using a different ball of the same brand for each subject, and each subject used the same ball for both testing sessions. Each subject provided his own driver, and the same driver was used for each testing session. Data were collected for 10 shots from each golfer. The reliability of the Vector launch monitor (Accusport) was established previously in our laboratory (Table 2)

Strength Testing. Torso, shoulder, and hip muscle strength were assessed with the Biodex System III Multi-Joint testing and Rehabilitation System (Biodex Medical Inc., Shirley, NY). Torque values were adjusted automatically for gravity by the Biodex Advantage Software v.3.2 (Biodex Medical). Calibration of the Biodex dynamometer was performed according to the specifications outlined in the manufacturer's service manual. Practice trials were provided for each muscle-strength test procedure to ensure subject understanding and familiarity. Practice included 3 submaximal contractions followed by 3 maximal contractions. Subjects were given a 1-minute rest following the practice trials. For actual data collection, subjects were instructed to perform a maximal effort with each contraction. Peak torque was normalized to body weight for all subjects. Measurements from the Biodex System III dynamometer have been found to be reliable (4). The reliability of strength testing using Biodex System III was established previously in our laboratory (Table 3).

For torso rotation testing, subjects were seated in an upright position and were stabilized with back and thigh stabilization straps. The rotational axis of the torso rotation attachment was aligned with the long axis of the spine of each subject. Subjects performed left and right torso rotations for 5 repetitions at 60°·sec^{-1} and 10 repetitions at 120°·sec^{-1}. There was a 1-minute rest between the 2 speeds of testing.

For shoulder testing, subjects were seated in an upright, comfortable position. The dynamometer was rotated to 20° and was tilted to 50°. The elbow of the subject was placed in the shoulder attachment so that the axis of rotation was the bisected shaft of the humerus. Torso straps were used to minimize extraneous movement. Each test was initiated with the shoulder in internal rotation, moving into external rotation. The subjects performed 5 maximal repetitions at 60°·sec^{-1}, and 10 repetitions at 180°·sec^{-1}. There was a 1-minute rest period between testing speeds.

Subjects were asked to perform isometric contractions of hip abduction and adduction with the greater trochanter aligned with the axis of rotation of the dynamometer resistance adapter. Subjects were tested in side-lying position with the hip joint in a neutral position during the testing of hip abduction (24). During the testing of hip adduction, subjects were placed at 20° of hip abduction in a side-lying position. Subjects also were secured using torso and pelvic straps in order to minimize extraneous body movements and momentum. Each subject performed 3 isometric contractions in each direction on both legs. Each isometric contraction lasted for 5 seconds. A 10-second rest interval was provided between contractions.

Balance Assessment. Balance was assessed according to the methods of Goldie (9, 10), using a Kistler force plate (Kistler Corporation, Amherst, NY) at the frequency of 100 Hz. Each subject was asked to complete a barefoot, single-leg standing balance test for each leg under 2 conditions (eyes open and eyes closed). Three 10-second trials were collected for each leg under each condition. During the testing session, the subjects were instructed to re-

TABLE 3. Physical characteristics reliability.*

Flexibility	ICC	*SEM* (°)
Shoulder flexion	0.984	1.920
Shoulder extension	0.938	1.418
Shoulder medial rotation	0.824	3.248
Shoulder lateral rotation	0.935	3.337
Hip flexion	0.940	1.846
Hip extension	0.855	2.318
Hamstrings flexibility	0.901	4.208
Torso rotation	0.863	4.587
Biodex System III strength testing	ICC	*SEM* (PTBW)
Left torso rotation, 60°·s^{-1}	0.906	12.4
Right torso rotation, 60°·s^{-1}	0.890	13.5
Left torso rotation, 60°·s^{-1}	0.944	12.4
Right torso rotation, 60°·s^{-1}	0.891	12.8
Shoulder internal rotation, 60°·s^{-1}	0.798	5.2
Shoulder external rotation, 60°·s^{-1}	0.384	5.8
Hip abduction (isometric)	0.647	15.8
Hip abduction (isometric)	0.856	14.8

* ICC = intraclass correlation; PTBW = peak torque/body weight.

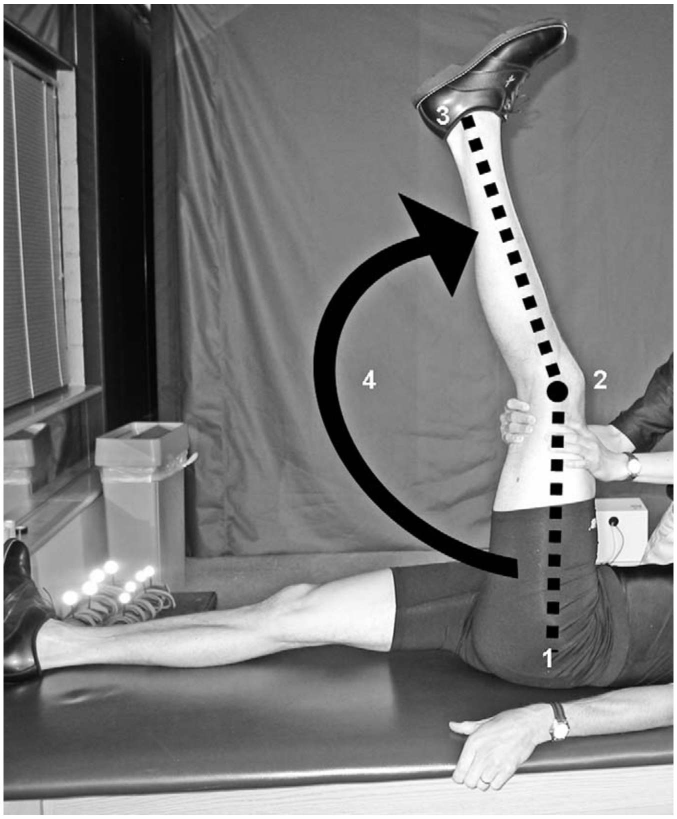

FIGURE 1. Active knee extension range of motion (ROM) is measured by creating a segment from the greater trochanter (1) to knee joint line (2), and knee joint line to lateral malleolus (3). The angle between the segments (4) is defined as the knee extension ROM.

main as erect as possible with feet shoulder-width apart and hands on hips. During the testing session with eyes open, subjects were instructed to focus on a target located approximately 2 m in front of them at eye level. During the testing session with eyes closed, the subjects were instructed to focus first on the target for balance, then close their eyes for data collection. This balance protocol has been established as reliable (9, 10).

Range-of-Motion Testing. Range of motion was measured using a standard goniometer. A small level was attached parallel to the stationary arm of the goniometer to verify correct orientation. Shoulder and hip joint flexibility were measured passively by the same physical therapist using the methods described in the textbook by Norkin and White (22). Hamstring flexibility was measured in a supine position using the active knee extension test. The knee flexion angle with the thigh in the vertical position was measured, so that complete extension was 0° (Figure 1). Torso rotational flexibility was measured actively from a seated position, allowing each subject to rotate his shoulders to end range while his pelvis was stabilized (Figure 2). The reliability of flexibility testing was established previously in our laboratory (Table 3).

Training

Subjects were enrolled in an 8-week conditioning program designed to enhance the stability of the lower body and to increase the mobility of the upper body. Specifically, the training program aimed to increase lower-body stability by increasing balance and hip strength while improving hip flexion and extension flexibility. The program aimed to increase upper-body mobility through increasing torso rotational flexibility and shoulder flexibility. Additionally, the program aimed to improve torso rotational strength. All subjects were tested prior to and following the 8-week conditioning program. At the conclusion of their first testing session, subjects received instruction on how to perform each exercise and were given printed and video instructions to aid them in performing the exercises independently. The exercise program is outlined in Table 4. Subjects received a 1.8-m piece of elastic resistance tubing attached to a handle and anchor piece for performing all strengthening exercises and a 20 × 25-cm soft foam stability training pad for performing the balance exercises. Subjects were instructed to perform the program 3–4 days per week. Flexibility exercises were performed by holding each stretch for 30 seconds. Strengthening exercises were performed using the elastic resistance tubing, with 2 seconds' concentric movement and 2 seconds' eccentric movement constituting 1 repetition. Three sets of 10–15 repetitions were performed bilaterally. Subjects were instructed to increase the resistance of the exercise

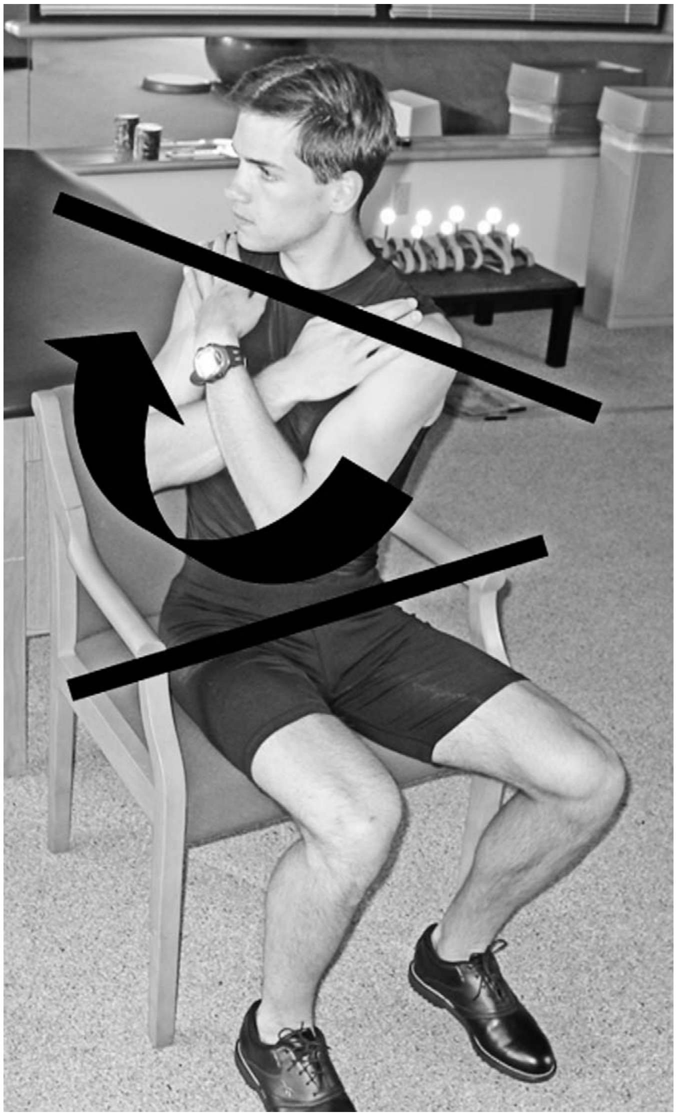

FIGURE 2. Torso axial rotation range of motion (ROM) is measured as a subject sits on a chair. As the subject rotates, the pelvis segment (1) remains stable while the upper torso segment (2) rotates. The difference between segments is the torso axial rotational ROM (4).

TABLE 4. Exercise program.

Stretching exercises	Description	Repetitions	Sets	Duration
Supine hip flexion	Lie on back, grasp knees, and bring to chest	1	1	30 s
Prone torso flexion	Keep hands and feet on the ground and create an "inverted-v" position with your pelvis and back	1	1	30 s
Kneeling lunge	Kneel with one leg, put other leg in front at 90° angle and push forward	1	1	30 s
Seated hip rotation	Cross one leg over the other and pull towards chest	1	1	30 s
Seated torso rotation	Cross one leg over the other and rotate torso in opposite direction	1	1	30 s
Seated torso rotation with club	Sit on a chair, hold a club behind your neck, and rotate torso	1	1	30 s
Standing lateral bending	Spread feet double shoulder width apart and laterally bend torso	1	1	30 s
Strengthening exercises				
Hip abductions*	Stand on 1 leg with elastic resistance tubing attached to the opposite ankle and abduct hip joint	10–15	3	2 s concentric 2 s eccentric
Hip adductions*	Stand on 1 leg with elastic resistance tubing attached to the opposite ankle and adduct hip joint	10–15	3	2 s concentric 2 s eccentric
Scapular retractions*	Kneel on floor, hold elastic resistance tubing in 1 hand and horizontally abduct the arm	10–15	3	2 s concentric 2 s eccentric
Resisted backswings*	Perform the backswing phase a golf swing using elastic tubing for resistance	10–15	3	2 s concentric 2 s eccentric
Resisted downswings*	Perform the downswing phase a golf swing using elastic tubing for resistance	10–15	3	2 s concentric 2 s eccentric
Resisted through-swings	Perform the through-swing phase a golf swing using elastic tubing for resistance	10–15	3	2 s concentric 2 s eccentric
Abdominal crunches	Lie on back with hips and knees at 90° angle and lift scapulae off the floor	10–15	3	2 s concentric 2 s eccentric
Balancing exercises				
Static front squat	While standing, squat until knees are at a 45° angle to the ground	1	1	30 s
Single-leg stances on floor	With hands on the hips, balance on 1 foot without letting opposite foot touch the ground	1	1	30 s
Single-leg stances on foam padding	With hands on the hips, balance on foam pad using 1 foot with hands on the hips without letting opposite foot touch the ground	1	1	30 s

* Indicates elastic resistance tubing is used when performing these exercises.

by moving farther away from the anchor point of the elastic resistance tubing when they could comfortably complete 3 sets of 15 repetitions of a given exercise. Two sets of balance exercises were performed for 30 seconds on each leg. Exercise logs from the subjects were collected by the investigators to determine subject compliance.

Data Analysis

Golf Swing Analysis. Anthropometric measurements and coordinate data collected from the optical camera recordings allowed for calculations of the center of rotation of the shoulders and of the segmentally embedded coordinate systems similar to those described by Vaughan (31). Three-dimensional coordinate data of the golf swing were filtered using an optimized cutoff frequency (14). The upper-torso segment was defined as the vector connecting the glenohumeral joint centers. Upper-torso axial rotation and pelvis axial rotation angles were calculated as the angle between the respective segment and the global x-axis, so that a completely neutral address position would be 0° of upper-torso and pelvis axial rotation (Figure 3). X-factor was calculated as the upper-torso axial rotation angle minus the pelvis axial rotation angle. Axial rotational velocity was defined as the rate of change of the axial rotation angle with respect to time. X-factor velocity was defined as the rate of change of the X-factor with respect to time.

The Vector launch monitor (Accusport) was used to determine the 5 shots with the longest driving distance for each subject based on the calculated driving distance. Kinematic data of each subject's 5 longest shots were averaged for data analysis.

Top of swing was defined as the transition between the backswing and downswing, when the club head changed directions. Impact was defined as the point at which the club made contact with the golf ball. Acceler-

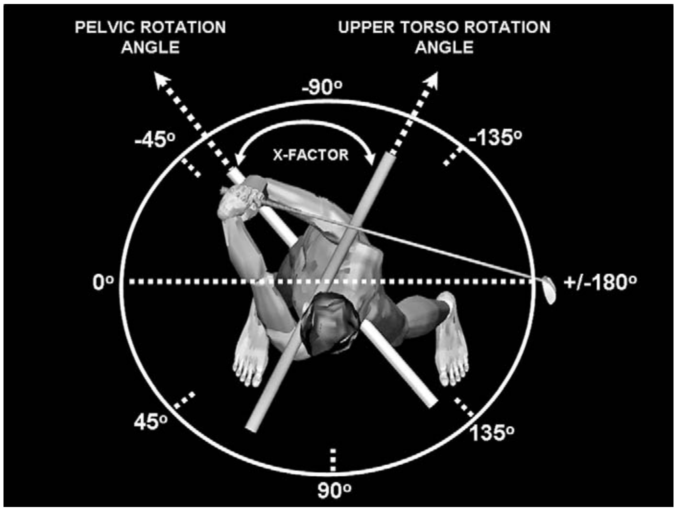

FIGURE 3. Overhead view of a skeletal model of a golfer defining the angles used in calculating rotational positions.

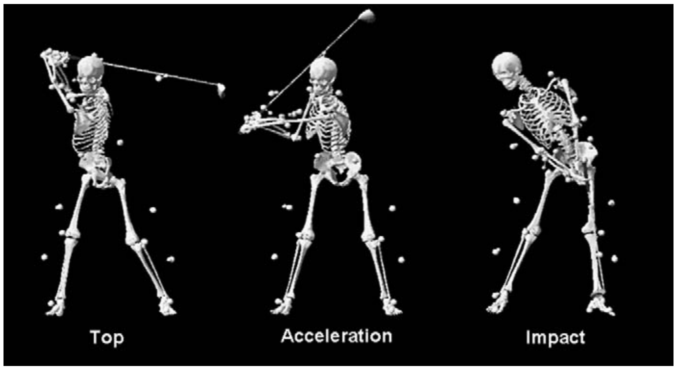

FIGURE 4. Front views of skeletal models demonstrating typical positions at the defined swing points.

ation was defined as two-thirds of the time between the top of swing and impact (Figure 4).

Balance Assessment. Ground reaction forces were calculated while standing on one leg on a force plate (Kistler) with eyes open and eyes closed. The standard deviation of ground reaction forces in the anterior-posterior, medial-lateral, and superior-inferior directions were calculated to define postural sway.

Statistical Analyses

The SPSS program (version 11.0; SPSS, Inc., Chicago, IL) was used for data analysis. The Kolmogorov-Smirnov test was used to determine if dependent variables were normally distributed. The Levene test was used to determine if there was homogeneity of variance. One-tailed paired *t*-tests were used to determine significant differences in all strength, ROM, balance, launch, and biomechanical characteristics variables. Statistical significance was considered at the $p \leq 0.05$ levels and a Bonferroni correction was used to account for alpha expansion for variables that were directly related to one another.

RESULTS

Tables 2–7 show the mean scores, standard deviations, percentage changes, and p values for physical, biomechanical, and launch characteristics. All data were distributed normally with homogeneity of variance.

Statistically significant improvements were observed for right torso rotation strength at both speeds and for left torso rotation at $60°\cdot s^{-1}$ (Table 5). There were no significant differences in shoulder rotational strength following the training protocol. Hip abduction strength significantly increased bilaterally, whereas hip adduction strength showed no significant changes. Statistically significant improvements were observed for all ROM tests (Table 6). Significant improvements in balance were seen: anterior-posterior sway on the left side in eyes-open and eyes-closed conditions and medial-lateral sway on the right side in eyes-open conditions (Table 7). All other balance variables were improved (p = 0.06–0.12), although these changes did not reach statistical significance.

Statistically significant decreases in magnitude (more open position) were observed for pelvis axial rotation angle at top of swing (Table 8). Statistically significant increases were observed for upper-torso axial rotational velocity and X-factor velocity at acceleration (Table 9).

Statistically significant improvements were observed for club velocity, ball velocity, carry distance, and total distance (Table 10). There were no significant changes in launch angle or backspin.

DISCUSSION

The golf-specific training program successfully improved a majority of physical characteristics in recreational golfers as hypothesized. All ROM variables showed significant improvement following our conditioning program, which is attributable to the program specifically targeting

TABLE 5. Mean ± *SD* strength values (peak torque/body weight).

	Pre	Post	% change	p value
Left torso ($60°\cdot s^{-1}$)	136.4 ± 33.1	149.7 ± 23.1	8.9	0.008*
Left torso ($120°\cdot s^{-1}$)	129.5 ± 24.2	137.1 ± 25.8	5.6	0.100
Right torso ($60°\cdot s^{-1}$)	137.1 ± 37.0	148.3 ± 27.6	7.5	0.009*
Right torso ($120°\cdot s^{-1}$)	125.0 ± 30.7	144.1 ± 28.6	13.3	0.002*
Left shoulder internal rotation ($60°\cdot s^{-1}$)	46.9 ± 11.7	48.2 ± 12.0	2.8	0.369
Left shoulder external rotation ($180°\cdot s^{-1}$)	34.8 ± 6.7	33.3 ± 5.0	−4.4	0.134
Right shoulder internal rotation ($60°\cdot s^{-1}$)	49.2 ± 9.9	49.9 ± 9.7	1.4	0.444
Right shoulder external rotation ($180°\cdot s^{-1}$)	35.2 ± 6.3	36.1 ± 4.3	2.4	0.319
Left hip abduction (isometric)	135.2 ± 32.7	148.0 ± 24.1	8.6	0.035†
Left hip adduction (isometric)	103.2 ± 27.3	112.1 ± 26.3	8.0	0.099
Right hip abduction (isometric)	134.3 ± 32.9	149.1 ± 22.8	9.9	0.023†
Right hip adduction (isometric)	118.1 ± 30.6	118.2 ± 29.4	0.1	0.457

* Indicates significant differences between pre- and posttraining results at $\alpha \leq 0.025$.
† Indicates significant differences between pre- and posttraining results at $\alpha \leq 0.05$.

Table 6. Mean ± *SD* range of motion values (°).

	Pre	Post	% change	*p* value
Left shoulder flexion	178.1 ± 11.1	184.9 ± 14.0	3.7	0.007*
Left shoulder extension	32.7 ± 6.8	42.6 ± 6.5	23.3	<0.001*
Left shoulder abduction	175.8 ± 15.8	191.8 ± 23.8	8.3	0.002*
Right shoulder flexion	177.4 ± 10.6	186.4 ± 12.8	4.8	0.001*
Right shoulder extension	30.8 ± 6.1	38.5 ± 9.0	19.9	0.002*
Right shoulder abduction	169.9 ± 16.4	187.2 ± 17.9	9.2	0.001*
Left hip flexion	133.7 ± 5.7	144.2 ± 4.6	7.3	<0.001*
Left hip extension	13.8 ± 6.2	21.5 ± 5.7	36.0	0.001*
Right hip flexion	131.1 ± 4.9	141.5 ± 4.3	7.4	<0.001*
Right hip extension	15.6 ± 3.0	25.3 ± 7.9	38.4	<0.001*
Left extension	22.7 ± 10.5	16.6 ± 12.2	−36.9	0.008*
Right knee extension	22.8 ± 11.6	15.5 ± 10.2	−46.9	0.002*
Left torso axial rotation	75.1 ± 5.6	83.1 ± 6.2	9.6	<0.001*
Right torso axial rotation	77.9 ± 6.2	84.2 ± 4.5	7.4	0.001*

* Indicates significant differences between pre- and posttraining results at α ≤ 0.05.

these movements. Significant improvements in torso rotational strength and hip abduction strength were observed. Shoulder rotational strength did not show significant improvements under any conditions. This is likely attributable to the program providing exercises emphasizing scapular stability rather than specific shoulder rotational movements. It is not clear why hip adduction strength and high-speed, left torso rotational strength did not improve. This may be attributable to differences between the motor patterns trained in the conditioning program and those tested on the dynamometer. These finding are consistent with the idea that motor learning markedly contributed to the improvements in strength. Increases in strength resulted from improved neuromuscular function; such improvements are important for optimizing golf performance, because they may increase the power of the swing without increasing muscle mass. Increases in muscle mass may be detrimental to golfers, because excess bulk can limit mobility and thus performance. Although body composition was not measured in this study, the nature of the exercises and the duration of the study likely would not produce significant increases in muscle mass. Balance variables under all conditions showed a trend for improvement, but only left eyes open and closed anterior-posterior reached statistical significance. It is possible that including a greater number of subjects would have resulted in statistical significance in balance variables.

Table 7. Mean ± *SD* balance values (standard deviation of ground reaction forces).*

	Pre	Post	% change	*p* value
Left eyes open AP	3.2 ± 0.8	2.7 ± 1.2	−18.3	0.009†
Left eyes open ML	4.0 ± 1.7	3.4 ± 1.8	−16.2	0.066
Left eyes open SI	5.7 ± 2.6	5.5 ± 3.7	−3.1	0.351
Left eyes closed AP	9.0 ± 4.1	7.0 ± 2.5	−29.4	0.008†
Left eyes closed ML	14.6 ± 6.6	13.1 ± 5.8	−11.6	0.076
Left eyes closed SI	25.5 ± 25.0	17.5 ± 8.5	−45.6	0.080
Right eyes open AP	3.1 ± 1.1	2.8 ± 0.8	−9.6	0.076
Right eyes open ML	4.2 ± 2.4	3.4 ± 1.0	−24.8	0.048
Right eyes open SI	5.8 ± 3.5	4.8 ± 2.1	−19.2	0.121
Right eyes closed AP	8.0 ± 3.4	7.8 ± 4.9	−1.8	0.409
Right eyes closed ML	13.8 ± 7.5	12.8 ± 8.1	−7.3	0.115
Right eyes closed SI	19.3 ± 11.7	18.6 ± 13.2	−3.8	0.354

* AP = anterior-posterior; ML = medial-lateral; SI = superior-inferior.

† Indicates significant differences between pre- and posttraining results at α ≤ 0.0167 (Bonferroni correction).

The training program resulted in some changes in swing mechanics even though this golf-specific program was not intended to specifically change the golf swing. Alterations in swing mechanics likely are not attributable to golf practice, because this study was conducted during the off-season, and golfers were not permitted to play golf or to practice at the driving range during their participation in the study. Improvements in swing kinematics may be attributable to motor learning effects combined with improvements in physical characteristics specific to golf. These resisted movements mimicked the golf swing, and this may have improved the sequencing pattern of the pelvis, shoulders, and arms. Improvements in sequence pattern may have resulted in greater mechanical efficiency in transferring power to the club and ball. Despite an increase in static upper-torso rotation ROM, our findings indicate that the magnitude of both upper-torso (nonsignificant trend, $p = 0.089$) and pelvis axial rotation (significant, $p = 0.031$) decreased at the top of swing. This is attributable to increased pelvic stability (a result of increased hip and torso strength) combined with increased torso flexibility. This combination of unrestricted movement of the upper torso with a more stable pelvis against which to rotate likely allowed golfers to achieve greater coiling of the body to generate more power. The decrease in pelvis axial rotation was greater than the decrease in upper-torso axial rotation, which increased the X-factor, though this was not statistically significant. Increases in the X-factor at the top of the golf swing have been suggested to be important for increasing driving distance (2). Furthermore, significantly increased torso axial rotation strength may have increased torso rotational torque, which subsequently increased upper-torso axial rotational and X-factor velocity at acceleration. Because the upper torso and the club are linked by the arms to act as a single unit, increased upper-torso axial rotational velocity likely is responsible for increased club head velocity.

Previous golf training studies have used changes in club head speed as the measurement of performance, with a range of improvements from 0.5–6.3% (3, 6, 13, 26). One recent study (7) reported a statistically significant correlation ($r = 0.95$) between a club head speed and low handicap scores. Our training program resulted in a 5.2% improvement in calculated club head velocity, which is consistent with other reported values. Additionally, we

TABLE 8. Mean ± *SD* torso rotational positions at top of swing (°).

Position at top of swing	Pre	Post	% change	*p* value
Upper torso axial rotation	−106.4 ± 9.5	−102.6 ± 8.1	−3.8	0.089
Pelvis axial rotation	−56.1 ± 10.8	−49.4 ± 6.8	−13.4	0.031*
X-factor	−49.8 ± 7.6	−53.5 ± 5.6	6.8	0.139

* Indicates significant differences between pre- and posttraining results at $\alpha \leq 0.05$.

measured ball velocity, carry distance, and total distance, which had improvements of 5.0, 7.7, and 6.8%, respectively. Significant changes in club velocity and ball velocity in the absence of significant alterations in launch angle and backspin indicate that carry and driving distance were improved solely as a result of improved club head velocity, resulting in improved ball velocity.

Whereas the primary purpose of the fitness and conditioning program was to improve golf performance, it also may play a role in preventing golf-related injuries. Golf-related musculoskeletal injuries commonly are due to overuse mechanisms and have been increasingly recognized by medical communities (11, 12, 25). Golfers with a history of low back pain have been found to have less hamstring flexibility (29) and less torso rotational flexibility than pain-free golfers (17, 28), and less torso flexion, extension, and rotational strength (17, 28). Although there is not yet adequate prospective research to determine if suboptimal physical characteristics increase the risk for development of low back pain in golfers, it is reasonable to believe that torso rotational ROM deficits may contribute to back injury. Golfers with limited torso rotational flexibility may exceed their physiologic ROM during the swing, resulting in high loads of stress on the vertebral column and associated structures (1, 17). Improvements in physiologic torso rotational flexibility combined with stronger torso musculature may allow these golfers to maintain their swing mechanics while decreasing the load placed on the spine, thereby decreasing the risk for swing-related back injuries (12).

Although this training program increased performance, there are some limitations to the study. The golf-specific training program was a home-based program. Subjects were guided initially through the exercises in person; they received printed and video instructions and were contacted biweekly to assess their progress. Although lack of direct supervision may be considered a limitation to the research, it is an asset to the program: it can be performed independently and, therefore, golfers may have greater compliance. This study design was pre- and postcomparison and a control group was not included. Thus, a learning or familiarization effect may have taken place, though this is unlikely because 8 weeks separated the 2 testing sessions. This is supported by previous studies that showed no learning effect after 5 (8) and 8 (6) weeks of training in control groups. Furthermore, we have found the measurements of our dependent variables to have high levels of reliability, as seen in Tables 1–3.

Our program is unique in that it was developed specifically to address limitations in physical characteristics of the average golfer. A comprehensive database of more than 100 golfers, with proficiency levels ranging from recreational golfers to Professional Golfers' Association touring professionals, was used to determine trends in physical characteristics by proficiency level. Exercises were created specifically to improve the physical characteristics in which average golfers were observed to be deficient, relative to elite amateur and professional golfers. Our program used elastic resistance tubing, which tends to be significantly less expensive and smaller than traditional strength training equipment. Furthermore, elastic resistant tubing allows individuals to perform exercises that mimic their swing mechanics with increased resistance, thereby optimizing functional strength by stimulating swing-specific muscles and the appropriate motor pathways (18). Lastly, the conditioning program's specificity to golf is likely to make the program enjoyable for golfers, which would increase the participants' commitment to the program and, therefore, maximize overall effectiveness (12).

The main findings of this study were significant improvements in multiple strength, flexibility, and balance measurements, accompanied by significant increases in upper-torso rotational velocity and X-factor velocity during the downswing, which resulted in increases in club head velocity, ball velocity, carry distance, and total distance. Future research may be directed at determining the specific relationships between physical characteristics and launch characteristics. Additionally, more advanced programs may be developed for golfers who have already attained a high degree of physical conditioning. This information could be used to create scientifically valid strength and conditioning programs to enhance golf performance and to reduce the risk for injury.

PRACTICAL APPLICATIONS

An 8-week golf-specific training program can improve strength, flexibility, and balance abilities, and these physical adaptations can improve golf performance. Because proficient golfers likely have optimized their physical characteristics for superior golf performance, they represent an optimal fitness level for recreational golfers to achieve. By targeting golf-specific physical limitations, golfers can develop a more stable base with greater functional flexibility. This combination allows for greater upper-body rotational velocities to be achieved, resulting in

TABLE 9. Mean ± *SD* torso rotational velocities at acceleration phase of swing ($°\cdot s^{-1}$).

Velocity at acceleration	Pre	Post	% change	*p* value
Upper torso axial rotation	588.4 ± 81.1	632.7 ± 87.9	7.0	0.009*
Pelvis axial rotation	384.8 ± 49.9	396.0 ± 63.4	2.8	0.346
X-factor velocity	203.6 ± 78.5	236.7 ± 68.5	14.0	0.037*

* Indicates significant differences between pre- and posttraining results at $\alpha \leq 0.05$.

TABLE 10. Mean ± *SD* launch characteristics values.

	Pre	Post	% change	*p* value
Carry distance (m)	193.7 ± 23.4	209.8 ± 25.8	7.7	0.001*
Roll distance (m)	13.7 ± 2.8	12.7 ± 2.5	−7.5	0.092
Total distance (m)	207.4 ± 23.1	222.5 ± 26.3	6.8	0.001*
Ball velocity ($m \cdot s^{-1}$)	60.7 ± 4.9	64.0 ± 5.9	5.0	0.001*
Club velocity	42.4 ± 3.3	44.7 ± 3.8	5.2	0.001*
Launch angle (°)	12.9 ± 3.6	13.2 ± 3.2	2.2	0.095
Backspin ($rev \cdot min^{-1}$)	3,138.8 ± 662.5	3,326.7 ± 624.6	5.7	0.198

* Indicates significant differences between pre- and posttraining results at $\alpha \leq 0.007$ (Bonferroni correction).

greater club head velocity. Therefore, it is recommended that golf coaches and teaching professionals add a golf-specific conditioning program to their current teaching and training protocols. Such a program has potential to improve the golf performance of already-proficient golfers.

The relevance of conditioning for injury prevention is applicable to the entire population of golfers, but it is especially important for both junior golfers during development and senior golfers. On the one hand, junior golfers participating in golf-specific conditioning may reduce their risk of injury and may increase their performance through optimizing their physical characteristics. On the other hand, age-related changes result in decreased flexibility (18, 21), strength (18), and balance (30). Thus, senior golfers who engage in a golf-specific training program may be able to limit age-related changes and thereby maintain greater overall health while improving their golf game. Combined, these factors may allow individuals greater enjoyment of golf with less fatigue and risk for injury (26). In turn, improving physical characteristics may allow individuals to play golf more regularly, thus enhancing their aerobic fitness (23) and overall health (19).

It is noteworthy that these results are reflective of 8 weeks of training in men who golf recreationally. Continued training may or may not result in further improvements in physical, launch, and biomechanical characteristics in this population. Golfers who are already well conditioned still may benefit from improved physical conditioning, and a basic program such as this one may not provide enough stimulus for performance enhancement in this population. Thus, more advanced golf conditioning programs may need to be developed to accommodate golfers who already have high levels of physical conditioning. This would allow for a progressive program whereby golfers can be challenged continually with different exercises of varying intensities. Additionally, development of multiple levels of physical conditioning programs would allow golf coaches and professionals the resources to personalize performance enhancement programs to specific individuals and populations of golfers.

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